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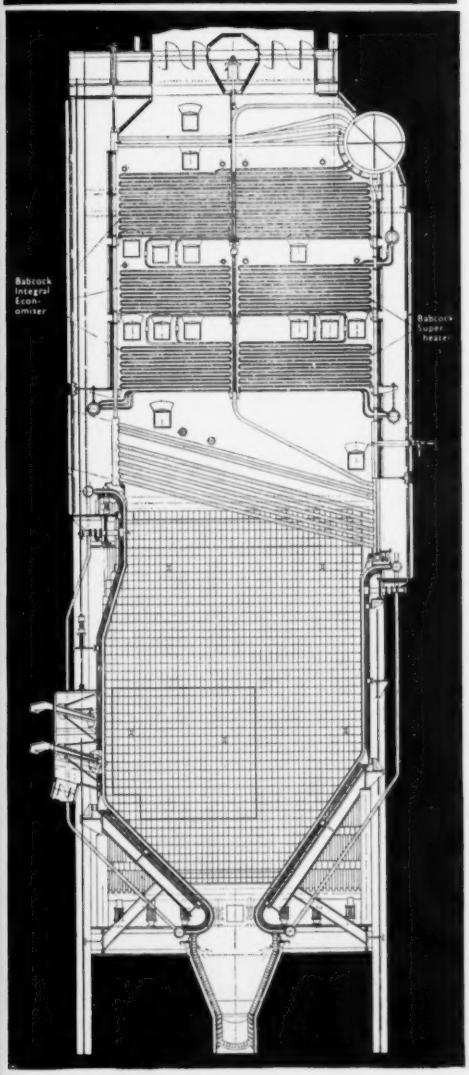

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10 High capacity turbulent burners forming an integral part of the furnace.
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12 Highest sustained efficiency throughout a wide range of load.
13 Bailey furnace construction permitting vertical, horizontal or opposed firing, depending on the nature of the fuel, and either ash discharge in solid form as in the hopper bottom furnace, or in liquid form as in the slag tap furnace.
14 A complete unit with all B. & W. equipment giving undivided responsibility in design and installation, supplemented with Babcock service.

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Plant	No. of Boilers	Load m.c.r. lbs/hr/blr.	Final Steam Pressure lbs/sq. in.	Final Steam Temperature °F	Furnace Construction
Brighton Corpn. Electricity Dept.	2	215,000	675	875	Bailey Hopper Bottom
Sydney Municipal Council, Bunnerong	4	350,000	650	850	do.
Phoenix Engineering Corpn. of New York for Shanghai Power Company	1	400,000	1,225	925	do.
Gemeente Electriciteits-Werken, Amsterdam	1	264,000	1,092	842	do.
Edmundsons' Electricity Corpn. Ltd. for South Wales Power Co. Ltd., Upper Boat Station	2	182,000	650	850	do.

Other recent orders for Pulverised Fuel Fired Boilers include :—

Plant	No. of Boilers	Load m.c.r. lbs/hr/blr.	Final Steam Pressure lbs/sq. in.	Final Steam Temperature °F	Furnace Construction
Manchurian Chemical Industries	1	264,000	520	820	Bailey Hopper Bottom
Broken Hill Pty. Co. Ltd., Newcastle, N.S.W.	4	110,000	450	775	do.
Beresnikovsky Chemical Combine, Beresniki, U.S.S.R.	1	330,000	839	842	do.
Manshu Dengyo Kaisha, Fushin Power Station, Manchuria	3	286,000	510	824	Bailey Slag Tap
Nippon Seitetsu, Yawata Steel Mill, Japan.	1	152,000	426	752	Bailey Hopper Bottom

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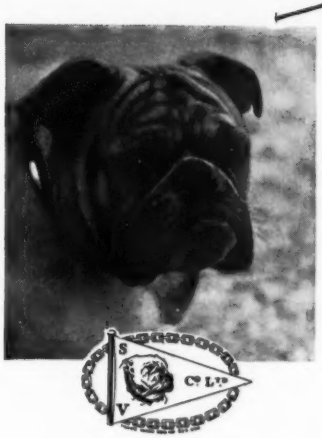

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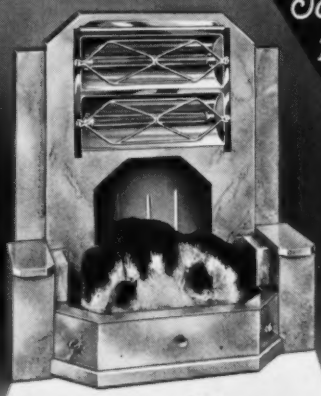

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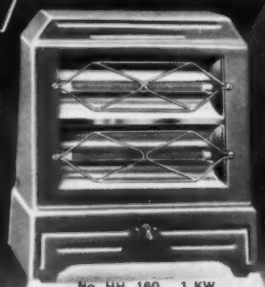

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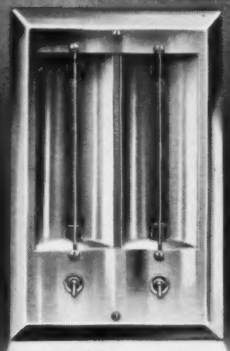

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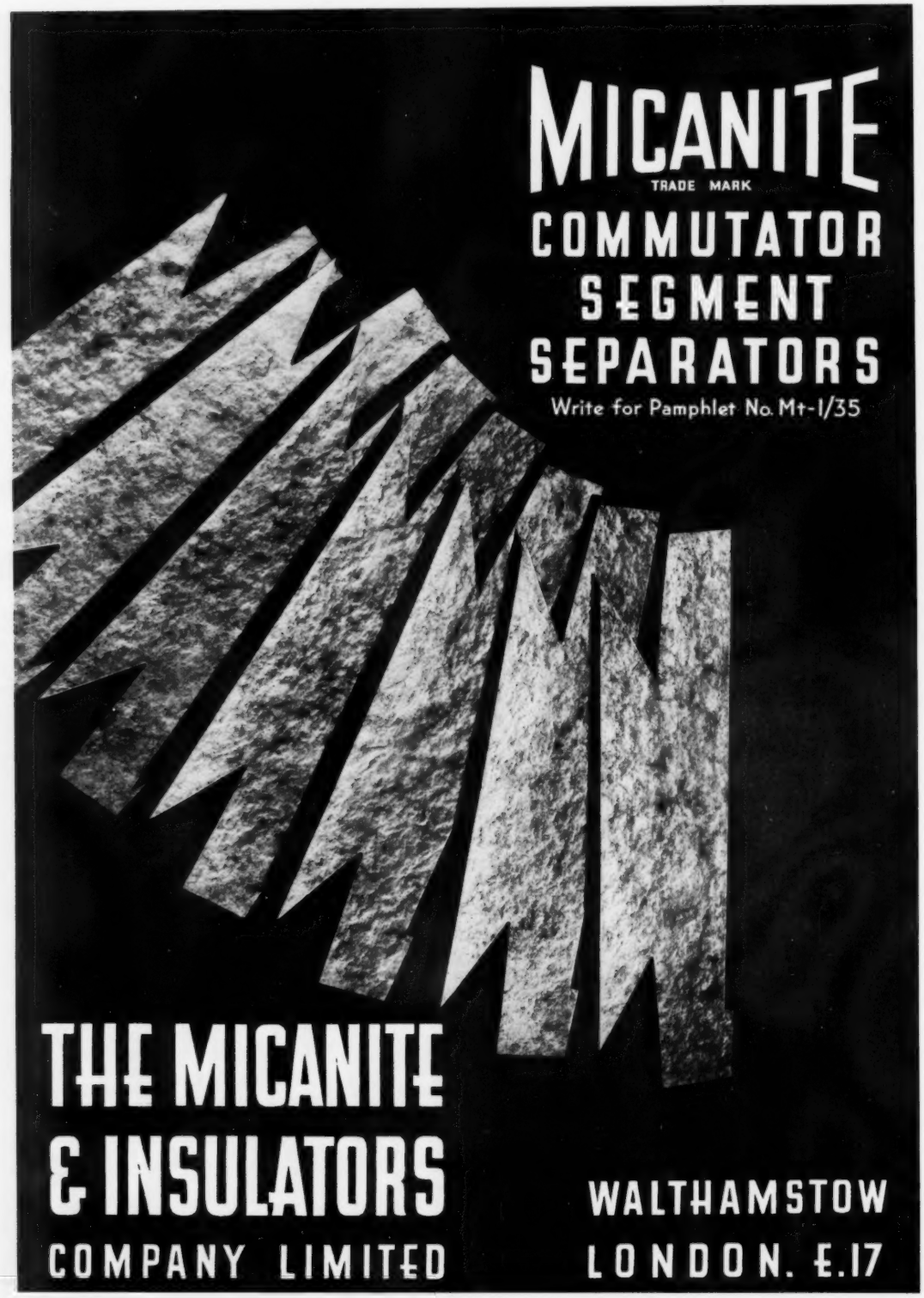
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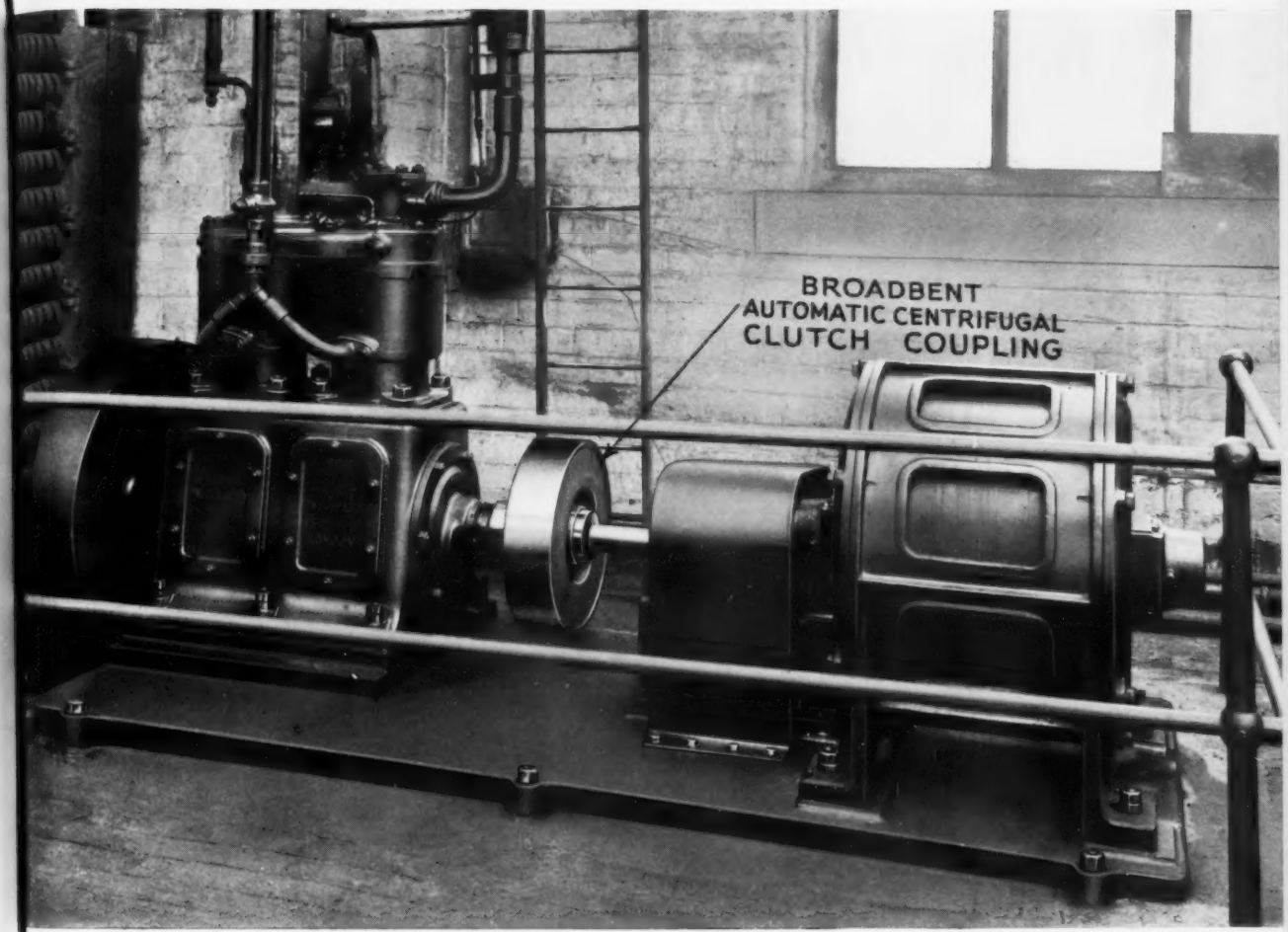

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These illustrations are typical of the two vehicles which will be shown on the Company's Stand No. 103.

The English Electric Journal

Vol. VIII. No. 7 SEPTEMBER/OCTOBER, 1937 One Shilling.

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All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD.

EDITORIAL.

In the first article Mr. R. M. Charley continues his series of articles on Scientific Developments in Transformer Construction. It deals with the problems of distribution of power to domestic consumers with particular reference to those located in rural areas. The Author mentions that with the ever-increasing connected load especially in the larger type of house, the 400-volt, three-phase four-wire system will eventually prove to be inadequate, and advocates a distribution system at 6.6 kV. This combined high-voltage and low-voltage distribution system is described and illustrated. It is pointed out that transformers for distribution service deserve as much consideration in their design as is given to larger units, and some very interesting figures are given justifying the adoption of electrical performance superior to that corresponding to the cheapest transformer that could be built.

On July 6th and 7th of this year the Company's Preston Works were visited by over 200 officials from Railways and

Transport organisations from all over the world. In the second article Mr. L. H. Short gives a brief outline of the visits and the principal contracts which visitors were able to see in course of manufacture in the shops. On the first day visitors were received by Mr. G. H. Nelson, Chairman and Managing Director, who in his speech of welcome emphasised the background of seventy years of experience of the Preston Works. On the second day visitors were received by Mr. H. T. Rice, Director.

The third article describes the Company's patented overhead busbar system for power distribution in factories containing machines with individual motor drive.

The layouts of industrial plant—particularly in the automobile and allied industries — are constantly changing owing to modifications in design and to the introduction of new machines and methods with the "English Electric" overhead Busbar System. The corresponding changes in electrical connections can be easily and quickly effected and can be carried out with safety while the busbars are "alive."

This issue is concluded with the first part of an article entitled Railway Electrification in Poland. The article gives a résumé of the factors which led to the £2,000,000 scheme for the electrification of the main Warsaw Junction Railways. A description of the substation equipment is given. The article will be concluded in the next issue and will deal with the overhead equipment, multiple-unit stock and locomotives.

One of three Diesel-Electric Locomotives for the Southern Railway proceeding under its own power over the London Midland and Scottish Railway Company's line for service in London on the Southern Railway system.

Scientific Developments in Transformer Construction.

By R. M. CHARLEY, M.C., B.Sc., M.I.E.E., Mem.A.I.E.E.

Our thanks are due to Messrs. Edmundsons' Electricity Corporation Limited for permission to publish certain pictures in this article and for details of the combined high-voltage and low-voltage distribution scheme described.

[*The first and second articles under this title were published in the September* (*Vol. VIII, No. 3*) *and December* (*Vol. VIII, No. 4*), *1936 issues of this Journal.*]

Previous sections of this article have been devoted to the larger transformers which are generally used for coupling power systems together, for transmitting power in bulk over long distances, or for giving a supply at comparatively high voltages to main distributing centres. An endeavour has been made to explain the problems that are met in the design of such transformers—which problems are mainly on account of the large size of the units—and the methods of solving them satisfactorily. Most of the power transformed by these transformers is eventually put to useful work at the usual distribution pressures, as, for example, 400 volts three phase. Some of the features that are of such great importance in large transformers must be considered for small units also, and other questions become of even greater importance with small transformers.

For distribution in fairly densely populated districts the 400-volt three-phase four-wire system is well established, but it is questionable if it will meet the demands for many years ahead, when there is evidence on every side that houses of the larger type may have an installed capacity of 15 kW. or even more. With the extension of such demands, the 400-volts distribution system will fail, and it will be necessary to develop a high voltage distribution system, at, say, 6.6 kV. or 3.3 kV., which, it is interesting to note, would be a revival of a scheme akin to house-to-house transformer distribution which was first used many years ago.

For distribution in rural areas the problem is not quite the same as for urban areas, but the necessity for the adoption of high voltage is present; probably the larger part of rural distribution is carried out at 11 kV., and there is an increasing tendency to tap even 33 kV. lines for comparatively small loads. Figs. 1, 2 and 3 illustrate 33 kV. transformers for such service, and Figs. 4 and 5 show actual installations of similar units in rural areas. It is interesting to note that the reliability of such transformers is so high that it is considered unnecessary to provide

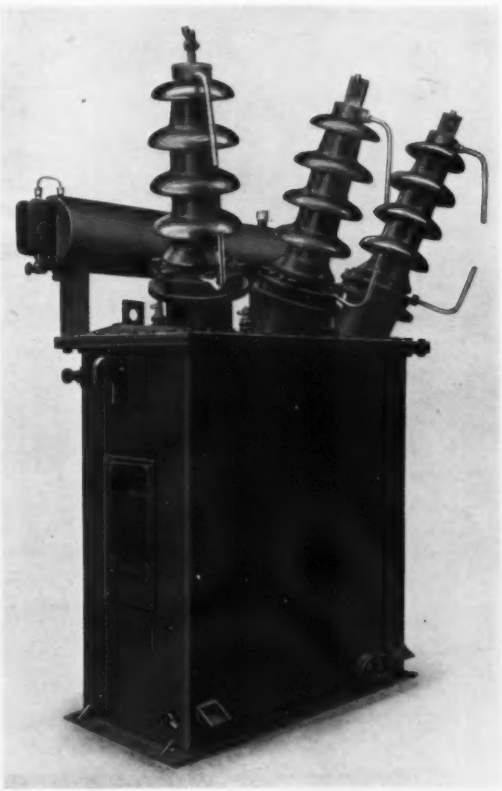


Fig. 1.—50 kVA. 33 kV. Three-Phase Transformer.

them individually with fuse protection on the H.V. side.

The tapping of 33 kV. lines can be justified in many cases in spite of the comparatively high cost of the transformers as compared with the cost of those for 11 kV. service. This cost increase is natural, for the higher voltage involves larger bushings, greater insulation clearances resulting in a bigger core, and, therefore, more copper, and also a larger tank ; the small current and large number of turns in the H.V. winding result in a lower space factor, again increasing the size of the parts. Consequently, the cost per kVA. rises at a rapid rate as the output is decreased ; for this reason, and also by determination as sound engineering practice, there is a minimum output of transformer that should be built for 33 kV. service. The curves in Fig. 6 give comparative cost per kVA. for three-phase and single-phase transformers, and it is strongly recommended that the minimum output should be 50 kVA. for three-phase units and 25 kVA. for single-phase units.

As in the case of urban areas referred to above, the ultimate distribution system is probably 400 volts three-phase, with direct transformation from 11 kV. or 33 kV. It was suggested that a system of high-voltage distribution may become

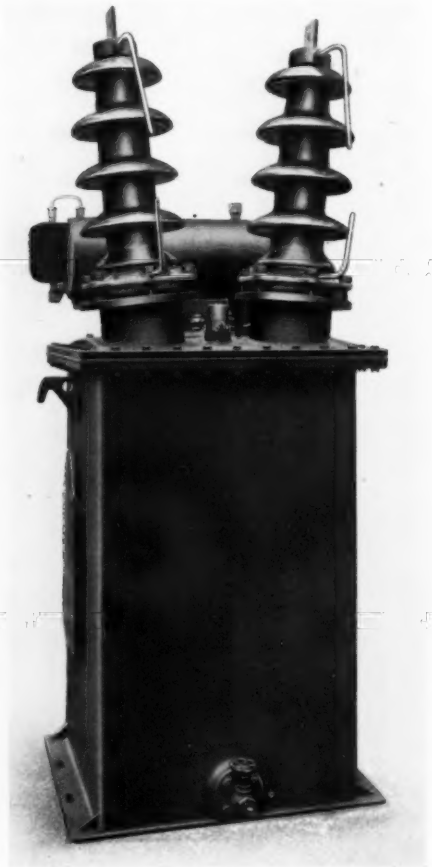


Fig. 2.—25 kVA. 33 kV. Single-Phase Transformer.

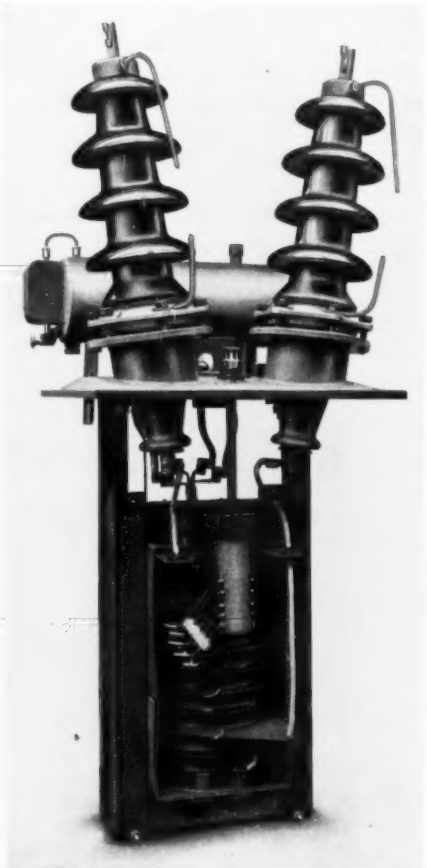


Fig. 3.—Transformer illustrated in Fig. 2 removed from its tank.

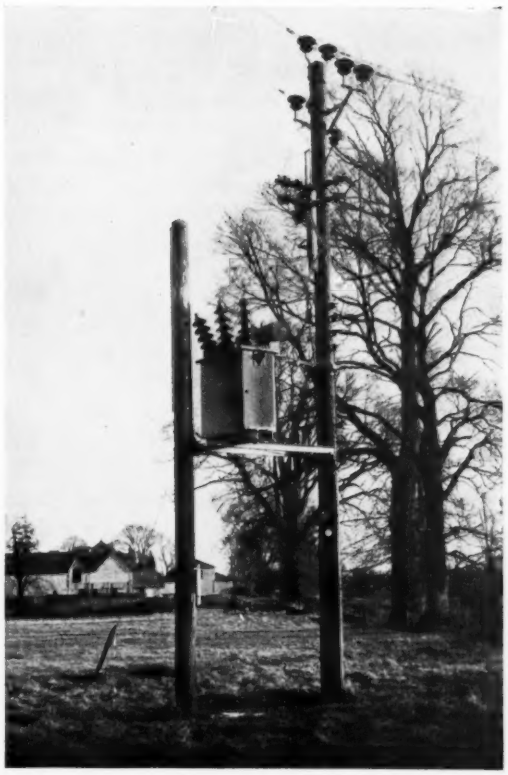


Fig. 4.—50 kVA. 33 kV. Three-Phase Transformer Installation.

essential with the increasing load ; such a scheme is now being adopted in rural distribution, not exactly for the same reason, but in order to make electricity supply in sparsely populated areas reasonably economical. A description of this scheme will be given later.

As stated above, transformers for distribution service deserve as much consideration in their design as do the larger units, and it is a fallacy to suppose that for rural distribution only the cheapest possible design should be adopted. It is intended now to describe certain features of construction and electrical characteristics which are recommended for transformers for rural distribution.

Apart from the question of iron loss, it is important that the flux density in the core shall not exceed, say, 11,000 lines per sq. cm. for transformers of outputs up to 50 kVA. and 12,000 lines per sq. cm. for larger sizes. Neglect of this feature results in the system becoming loaded up with wattless current in which harmonics form an unreasonably large proportion and noise emission may be objectionable.

Since the load factor on a rural scheme is probably very low, it is important that the iron loss on transformers shall be reasonably low. Furthermore, it is interesting to note that a kilowatt of iron loss costs just as much to supply to a small distribution transformer as to a large power transformer, and, again, the iron loss as a per-

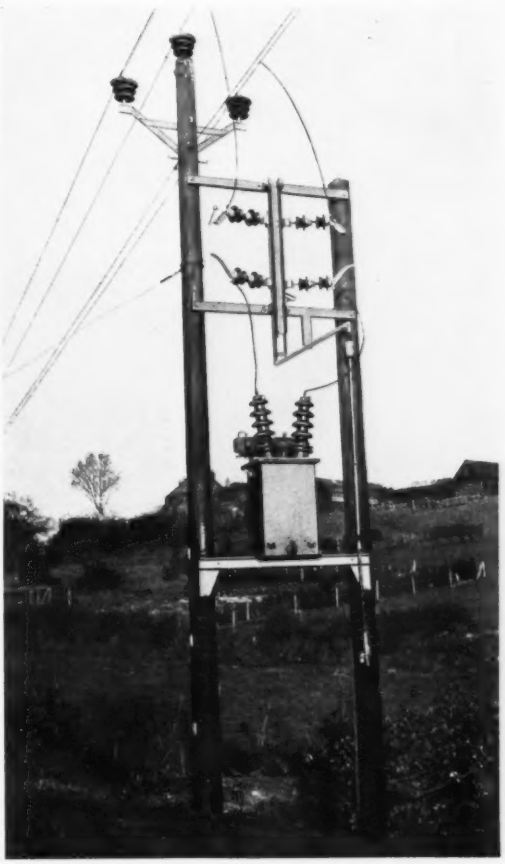


Fig. 5.—50 kVA. 33 kV. Single-Phase Transformer Installation.

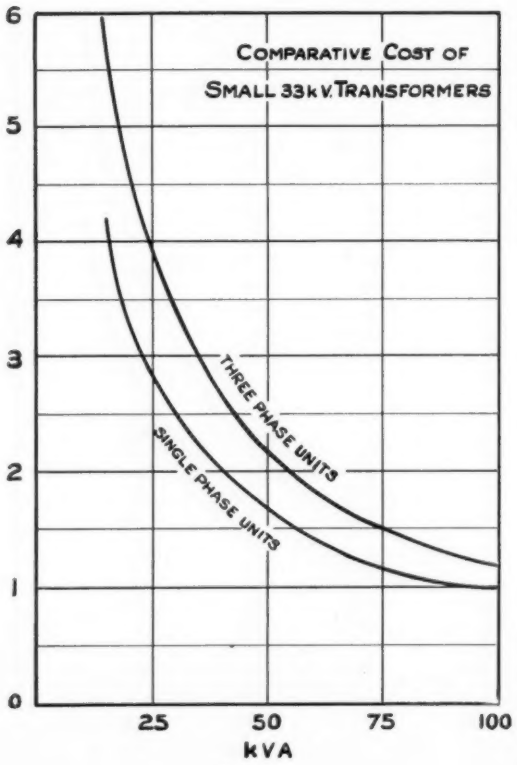


Fig. 6.

centage of the output is much greater in the former than in the latter. Consider that a 5,000 kVA. transformer is supplying a distribution system on which there is a total capacity of 5,000 kVA made up of a number of units having outputs up to 250 kVA.; the iron loss of the former is about 12 kW., and the aggregate for the latter is about 30 kW. Such considerations indicate that the iron loss is a very important factor, and while no universal formula can be given for its evaluation, there is no doubt that, in general, a lower value than normal may be justified.

In the past, copper loss has been disregarded or given scant consideration because it was realised that it varies as the square of the load and that the load factor on distribution systems is very low. But this is only one aspect of the matter, and consideration of other factors indicates that the value of low copper loss may rank almost equally with that of low iron loss. In addition to the cost of the loss itself, the fact that it increases as the square of the load means that it has a serious effect on the maximum demand, which is an important factor in tariff charges.

Another effect of copper loss is in relation to voltage regulation. An approximate formula for the percentage voltage regulation at rated load and unity power factor is given by :—

$$E_R\% + \frac{(E_X\%)^2}{200}$$

where $E_R = \frac{W}{I}$.

W = Watts measured on short-circuit test corrected to 75 deg. C., and to rated current of winding I.

E_X = Reactance voltage as calculated from the impedance voltage measured across winding excited on short-circuit test.

Remembering that on the comparatively small transformers under review the copper loss has a comparatively high value as a percentage of the output, and that the reactance is relatively small, it is seen from the formula that the copper loss has a predominating influence in determining the voltage regulation at unity power factor. It is reasonable to assume that the type of load on a rural scheme results in a power factor near unity. A 25 kVA. three-phase 11 kV. transformer has copper loss and reactance values as follows :—

W = 200 watts per phase.

$E_R = W/I = 200/.758 = 264$ volts.

$$E_R\% = \frac{264 \times 100}{11{,}000} = 2.4\%.$$

$E_X = 305$ volts.

$$E_X\% = \frac{305 \times 100}{11{,}000} = 2.77\%.$$

* Regulation at Unity Power Factor

$$= 2.4 + \frac{2.77^2}{200} = 2.44\%.$$

* *For complete details of this formula see B.S.S. 171/1936 Appendix E.*

This figure for voltage regulation at unity power factor is little more than the percentage value of the copper loss.

The force of this argument is that the voltage at consumer's terminals drops by at least the amount of the voltage regulation of the transformer ; the unfortunate result of this is that the energy consumed is correspondingly reduced with the inevitable reduction in the revenue of the supply authority. Another factor is that if the voltage regulation is not good, the consumer will have a justifiable reason for making a complaint against the service.

There is, therefore, good reason for building transformers for rural distribution service with lower copper loss than normal.

In the foregoing, arguments have been put forward justifying the adoption of electrical performance superior to that corresponding to the cheapest transformer that could be built ; mechanical construction is also of importance, and similarly a more expensive design is warranted by the increased reliability in service achieved thereby. Figs. 7 and 8 illustrate a construction that should be used for transformers for rural distribution service.

Such a transformer should be looked upon as a unit, not a core and windings as a separate entity from the tank. If there is a suspicion that a fault has developed, it is of doubtful value to be able to examine and test the core and windings while the transformer is *in situ*, for it is extremely improbable that it could be repaired without removal to a repair shop ; therefore, it should be replaced by a sound unit without delay. This principle is followed in the design under consideration, and the only feature that is capable of repair *in situ* is the bushing, for it is realised that these may be damaged without any fault being sustained elsewhere in the transformer. All H.V. and L.V. bushings are mounted in the cover and are capable of replacement without disturbing the cover, after the withdrawal of a small quantity of oil from the tank. The construction of a typical 11 kV. bushing is shown in Fig. 9. The porcelain is a single piece, to which is cemented the flange and top cap. The conductor is a stranded cable with reinforcement around the portion near the flange, and the end is sweated into a socket passing through the top main cap, to which is bolted a detachable auxiliary cap. It is seen that by removing the detachable cap, the nuts on the cable socket and the studs of the flange, the porcelain may then be removed, and a new porcelain can be threaded over the cable and the whole bushing reassembled. The construction of the L.V. bushings is on the same principle, but the conductor is a rigid stalk.

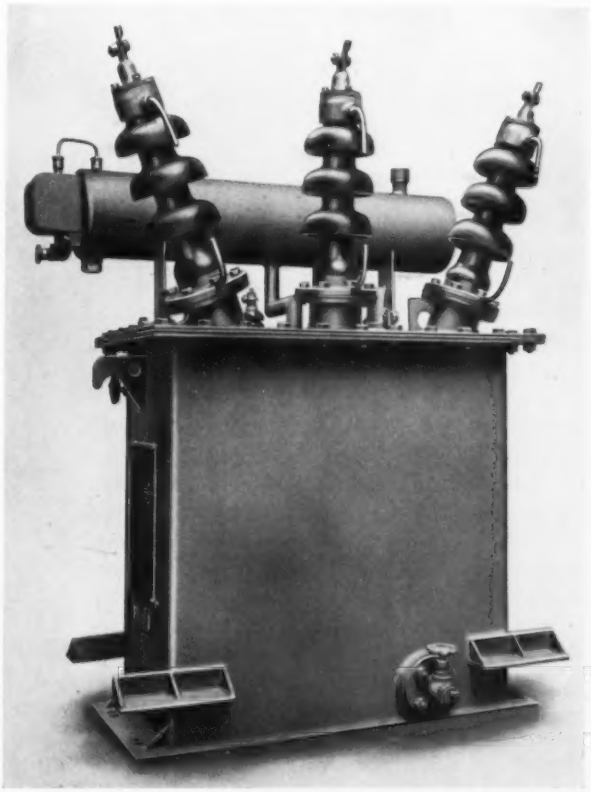


Fig. 7.—25 kVA. 11 kV. Three-Phase Transformer.

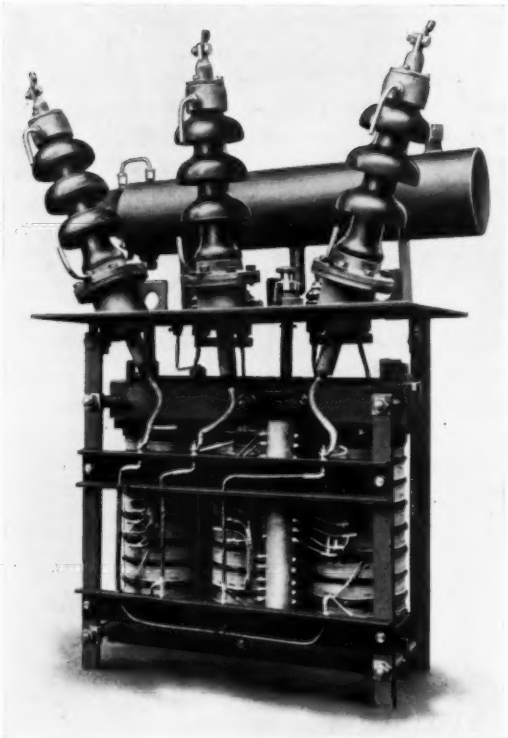


Fig. 8.—The Transformer illustrated in Fig. 7 removed from its tank.

The important feature of this construction is that the tank is maintained full of oil by the use of an expansion vessel. The value of this principle is well known in that the dielectric strength of the oil is retained for a longer period, and the possibility of a flashover inside the tank is very remote, and since all terminal and cover gaskets are subject to oil pressure from inside, entrance of moisture is rendered impossible. But, whereas it has been generally admitted by users that such construction is justified for large transformers, or for units for operation at pressures above, say, 33 kV., the practice has not been adopted in this country to the large extent that is the case in other European countries. The policy of The English Electric Company is that this useful construction should become standard for all transformers for outdoor service.

Tappings have usually been specified for distribution transformers, but it is doubtful if they have been used to the best advantage owing to a tapping-switch not having been provided. It is to be recommended, therefore, that all such transformers should be supplied with an off-load tapping-switch capable of operation from outside the tank. Fig. 8 shows such a tapping-switch on a three-phase transformer, and Fig. 10 illustrates the construction. The tappings are connected to a series of spring finger contacts bolted at one end to the inside of a bakelised paper tube, the movement of the other end being restrained by a stud passing through a hole in the tube with a nut on the outside. This feature is clearly seen in Fig. 8. Connection between contacts is achieved

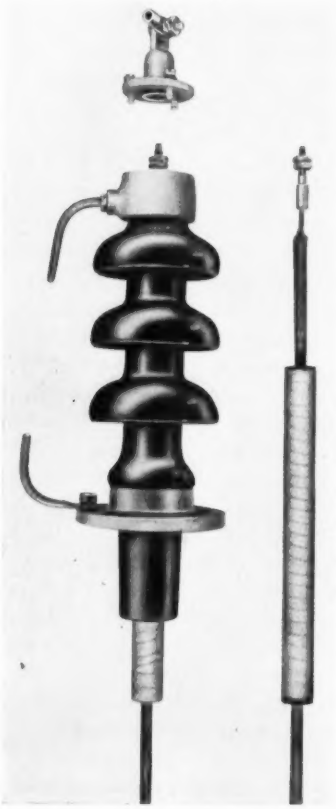


Fig. 9.—Assembly of 11 kV. Bushing.

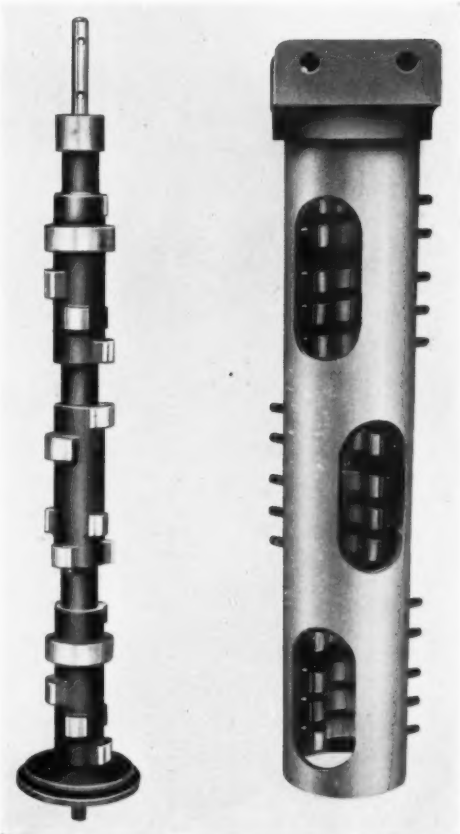


Fig. 10.—Details of Tapping switch for an 11 kV. Three-Phase Transformer.

through a metal cam-contact-block seen on the left of Fig. 10. The contact blocks for the three phases are mounted on a single bakelised paper tube fitted at each end with metal parts to provide bearings in the centreing members located at each end of the main tapping-switch cylinder. A simple universal coupling connects this shaft to the shaft of the operating handle located in the cover, this shaft passing through an oil-tight gland. To rotate the switch the handle is raised against the pressure of a spring until a spigot is free from a hole in the block under the handle; this spigot definitely locates the switch for each tapping position. A cover is provided over the handle as seen in Fig. 7, and the design is such that the thumb screw fixing the cover cannot be inserted unless the tapping-switch is in a correct position.

Fig. 8 shows how the cover is supported above the core with suitable adjustment of the supporting members; the expansion vessel is also mounted on the cover. The resulting construction follows the principle of the transformer being a single indivisible unit.

Transformers constructed as described above, although somewhat more expensive than the cheapest design, are strongly recommended for rural distribution service.

Figs. 11 and 12 show 11 kV. transformer installations in rural areas.

It may be of some interest to refer to a scheme for rural distribution that bids fair to improve service conditions in many difficult cases, and to justify others where otherwise a supply of electricity could not be made an economical proposition. The scheme involves a transformer construction on rather novel lines, which will be described later. Much has been done by Supply Authorities to make electricity supply available to the whole population, but it must be admitted that regulations have, to some extent, hampered such efforts. The Home Office and other Authorities are now prepared to relax some regulations, and there are very hopeful signs of co-operation between the Supply Authorities, the Post Office and Home Office, which will go a long way towards making rural electricity supply economical, and without having any adverse effect on the efficiency of the Post Office service or the amenities of the district.

As stated earlier in this article, it was realised that distribution at 400 volts three-phase or 230 volts single-phase would seriously restrict expansion of supply in many areas, and, therefore, more feeding points would have to be provided. It can readily be understood how difficult this becomes under some rural conditions that are quite common, and even more so when the supply to the area is at 33 kV. A solution to this problem

was to run a new high-pressure supply on the same poles as the low-voltage distribution wires, but before this could be accomplished the sanction of the Electricity Commissioners had to be obtained, and agreement had to be secured from the Post Office Engineers to modifications of several of their conditions. However, such difficulties have been very largely overcome by reciprocal accommodation, and Messrs. Edmundsons Electricity Corporation, Limited, have obtained approval for a design which they are using extensively, not only for opening up new thin rural areas, but also for converting existing

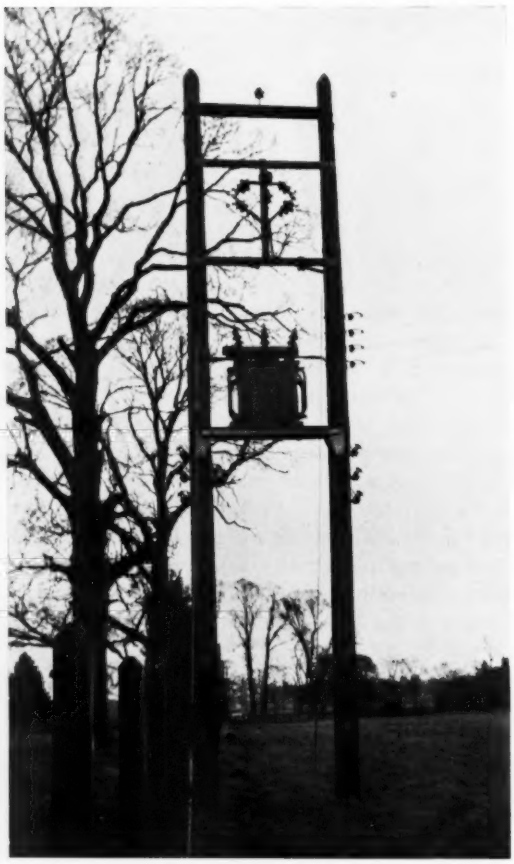


Fig. 11.—50 kVA. 11 kV. Three-Phase Transformer installation.

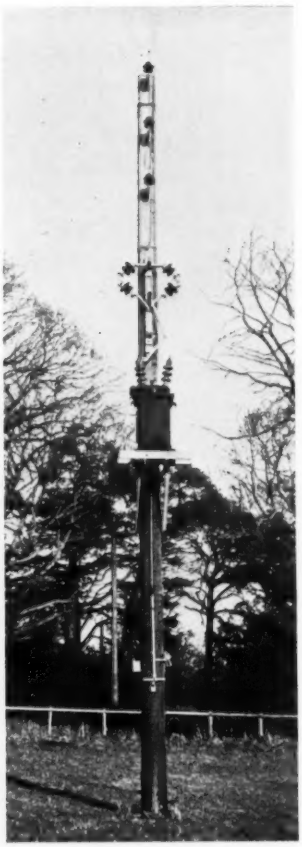


Fig. 12.—15 kVA. 11 kV. Single-Phase Transformer Installation.

schemes in villages where growth of load has rendered one or more feeding points essential. In Fig. 13 will be seen Mr. Morley New, one of the Electricity Commissioners, on a tour of inspection of one of these schemes.

Obviously, the determination of the voltage for this high-pressure distribution needed careful consideration because of the basic principle that the high and low-voltage distribution wires must be run on the same poles, and also that the Post Office lines may run parallel to and in close proximity with the power lines, in which case it would be deemed advisable to limit the high-voltage distribution pressure. By mutual agree-

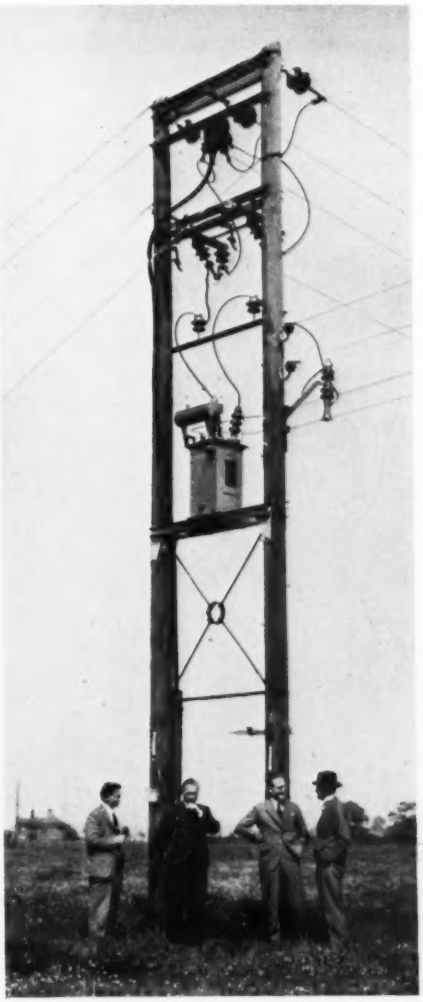


Fig. 13.—Main Stepdown Transformer for combined high-voltage and low-voltage distribution.

ment, it was decided that the pressure should not exceed 6.6 kV. three-phase or single-phase. Other reasons for limiting the voltage to this value are (1) cost of transformers, and also their size and weight as affecting general appearance and pole size, (2) conductor spacing also affecting pole height and neatness of construction, (3) that the insulator ironwork could be unbonded, thus eliminating bird trouble.

Fig. 14 shows the pole arrangement for a single-phase scheme, including the mounting of the transformer. Lines originally erected for single-phase supply only are designed to be easily convertible to three-phase high and low-voltage distribution later.

An important feature of the scheme is the earthing of the high-voltage system, which is provided only at the main step-down transformer. For single-phase schemes one line terminal is earthed and for three-phase schemes one phase

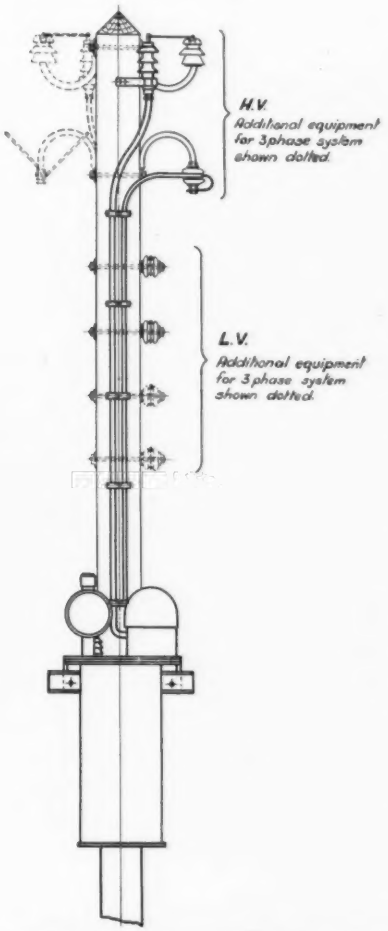


Fig. 14.—Typical Transformer Pole Arrangement for combined high-voltage and low-voltage distribution.

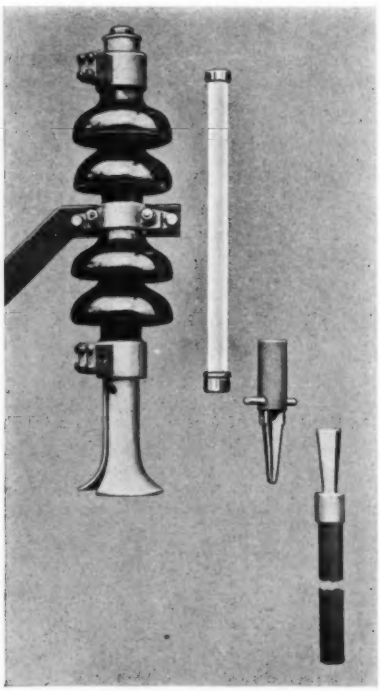


Fig. 15.—Type R.D. Pole-Operated Fuse Unit for rural distribution.

terminal is earthed. This method of earthing provides an earthed wire throughout the length of the line without the necessity of running an additional wire for earthing purposes. It is important to remember that this condition of service is more onerous on the insulation of the transformer than in the normal case, e.g., with a three-phase unit, the maximum voltage to earth is the line voltage divided by $\sqrt{3}$, whereas under the condition just mentioned the corresponding voltage is $\sqrt{3}$ times as much. This condition must be legislated for in the design of the transformer and appropriate tests must be applied. (See B.S.S. 171/1936, Table 9 (1), Test (A).)

Transformers required for such schemes are of two kinds : (1) a supply unit located at the main tapping point to reduce the pressure from, say, 33 kV. to 6.6 kV. (2) high-voltage distribution units, several of which will be located along the distribution pole line. Transformers in class (1) are standard distribution units in all respects except that the insulation must be made suitable for the special service conditions as described above.

The high-voltage distribution line is controlled through an " English Electric " R.D. fuse fitting, which has proved so popular for rural distribution service generally. It may be seen in Fig. 13, and a single-phase unit in detail is illustrated in Fig. 15.

In class (2) the transformers must be as inexpensive, simple and light as possible, while still

Fig. 16.—5 kVA. Single-Phase Transformer for combined high-voltage and low-voltage distribution.

retaining the necessary features, both electrical and mechanical, emphasised previously for general adoption. Usually, it can be assumed that the voltage drop in the high-voltage distribution line is negligible and that the length of section in the low-voltage line is very short, and, consequently, it is agreed that tappings on these transformers may be omitted. The transformer is hung on the pole below the low-voltage distribution wires, the "live" connection is made by means of single-core lead-covered cambric-insulated cable, and by rubber-insulated and braided cable for the earthed connection. The transformer terminals are porcelains mounted in the tank-cover, and, in order to comply with the Electricity Commissioners' regulations, are completely protected by a metal hood through which the connecting cables are brought through suitable cable glands. Such a single-phase transformer, with the hood moved to show the H.V. terminals, is illustrated in Fig. 16, and a similar unit *in situ* in Fig. 17. These high-voltage distribution units are connected to the line on the H.V. side without any fuse protection.

The low-voltage system neutral is connected through an earthing test-link to a bare copper wire buried in the ground commencing from the pole adjacent to the transformer pole. Normally, each transformer has its neutral terminal earthed, and it supplies into its own isolated section of the low-voltage distribution line. Should it be deemed desirable to couple sections together, this may be carried out by means of a light fuse situated approximately midway between two feeding points, but in this case all earthing links but one must be removed unless authority for multiple earthing has been obtained from the Electricity Commissioners. The transformer tank and sheath of the lead-covered "live" cable must be earthed at the transformer pole.

It will be apparent from the above that the scheme described is not necessary for a supply to an isolated group of houses located fairly close together, and which can all be fed economically from one point, but it is ideal for extended sparsely populated districts, and particularly for ribbon housing development. Attempts to force the use of low-voltage distribution too far are to be deprecated, for such practice may result in poor service to consumers and reduced revenue to the Supply Authority, with the resulting lack of incentive to expand rural electrification. General distribution should not be carried out at less than 11 kV. and even 33 kV. will be found economical in many cases : the combined high-voltage and low-voltage system of distribution at 6.6 kV. will find a wide field of application in the development of rural areas.

Fig. 17.—5 kVA. Transformer Installation for combined high-voltage and low-voltage distribution. Electricity Commissioners and Messrs. Edmundsons' Engineer on a tour of inspection.

Visit to the Rolling Stock and Vehicle Body Works, Preston.

By L. H. SHORT, M.C., A.M.I.E.E., A.M.Inst.T.,

The progress which has been made in Diesel Traction and in the construction of lightweight all-metal rolling stock during the past few years has been considerable, and marked interest is taken in these new forms of transport by Traction Operators in all parts of the World. The Preston Works of the Company have been associated with these developments since their inception, and in view of the large contracts in hand it was felt that the work in progress would be of interest to visitors. The works were, therefore, made available for inspection on two consecutive days during the early part of July and the fact that over 200 officials from Railways and Transport organisations made the journey to Preston may be taken as an indication of the successful nature of the visit.

The parties included many distinguished visitors from all over the world, including representatives from Australia, Burma, India, Ceylon, Egypt, Iraq, South Africa, Rhodesia, Sudan, New Zealand, West Africa and South America, and from Great Britain.

On arrival at Preston the visitors were received

Fig. 1.—Aerial View of Preston Works.

on the first day by Mr. G. H. Nelson, Chairman and Managing Director, and on the second day by Mr. H. T. Rice, Director. In his brief speech of welcome the Chairman said :—

" Gentlemen, on behalf of my Company I have the greatest pleasure in welcoming you to these works and have to thank you for coming. If you will allow me I will tell you a little of their history.

" The ground you are actually standing on and the works on the left are the oldest works in our Company. They have been standing for upwards of seventy years and in these works you will see mainly road vehicles. On the other side of Strand Road, which was at one time one of our electrical engineering works, we have laid out the shops for the manufacture of lightweight rolling stock, and equipped them with the very latest plant and material.

" It is perhaps of interest to make a comparison—you may know that the weight per passenger of some of the American Railroad vehicles is in the neighbourhood of 2,500 lbs. per passenger, the weight per passenger of some of our latest vehicles which you will see whilst in these shops is in the neighbourhood of 550 to 600 lbs.

" The background at these works, as I have mentioned, is seventy years of experience. In the engines, which you will see in the cars on the other side, is also a long engineering experience. Our Willans Works, Rugby, were established sixty years ago and in those works Diesel engines have been manufactured for the last thirty years. We are the second oldest manufacturers of Diesel engines in this country. To give you a picture of development over those years (and here again I make an interesting comparison), I would mention that the first Diesel engine we made had a weight of 400 lbs. per horse power, whereas in the coaches we are building for the Ceylon Government Railways the weight of the Diesel engine is 23 lbs. per horse power.

" You will also see electrical equipment. Most of you will know that Dick, Kerr & Company were the pioneers in railway electrification and the Company have continued in that tradition. At the present time we are fortunate in having a contract for the Southern Railway. We are manufacturing rolling stock equipment for them on a ten years' basis—that is the confidence the Southern Railway have in our tradition and in our products. It is also a pleasure for me to tell you that we have recently received an order from the London, Midland & Scottish Railway for the re-equipping of the Liverpool—Southport sections

Fig. 2.—Body-building Bay showing welded body framing prior to panelling.

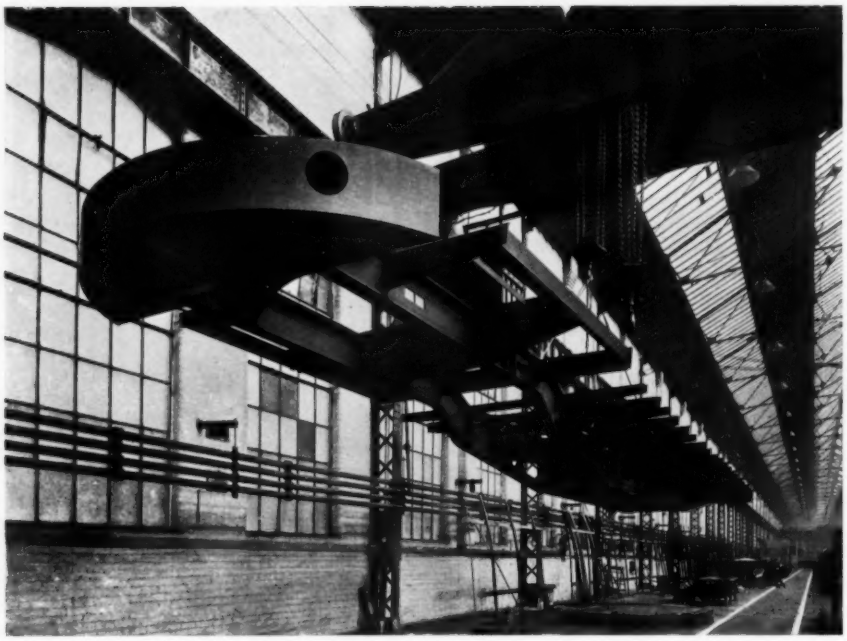


Fig. 3.—Ceylon Government Railways 4-coach articulated trains. All-welded underframe for power coach.

which we electrified 34 years ago. That will give you an indication of the life of our material.

"Finally, a fact that you may be interested in, is that the inspection at our works is completely under Lloyds' supervision. The object of that has been to divorce our inspection completely from our management, to ensure that we produce the best material and that by having Lloyds in control we obtain what we desire and that you receive the best product obtainable."

The visitors were then conducted through the shops in small groups, a guide being appointed to each group. The following work was inspected :—Articulated streamline trains for the Ceylon Government Railways, main line express passenger locomotives for the New Zealand Government Railways, Diesel-mechanical rail coaches for the Buenos Aires Great Southern, the Buenos Aires Western, and the Entre Rios Railways, Diesel-electric locomotives for the Southern Railway, Diesel-mechanical locomotives for works and shunting purposes. Rolling stock for the Federated Malay States Railways, suburban electric trains for the New Zealand Government Railways, underframes and body-framing for double-deck tramcars, and a large number of trolley and motor bus bodies for municipal and private operators in this country.

The Ceylon units were of special interest as they are the first four-coach articulated Diesel-electric units to be built in this country, and are wholly of this Company's manufacture. In order to reduce wind resistance a fully streamlined form has been adopted. The seating capacity is 300, 1st, 2nd and 3rd class passengers, and the total weight of a loaded four-coach train is 112 tons.

It was interesting to note the similarity in the body-framing of these trains and of the all-metal bus body framing. Restriction in weight of the all-metal bus body, on account of the Ministry of Transport's weight regulations, has made it necessary to employ very light gauge sections and considerable investigation has been necessary to ensure complete protection against corrosion of

the light sections employed. This has now been satisfactorily achieved and the experience gained in this construction has been applied to railway practice although heavier gauge sections are normally used.

The attractive appearance of the modern road vehicle has also made its mark on the new railway stock, and there is no doubt that the judicious mixture of the more orthodox type of railway construction with that of the road vehicle has been responsible for the modern design and construction of these units.

In the Ceylon units the whole structure is fabricated by welding. The panels and the sections are of copper bearing mild steel, and the panels are attached to the framing members by means of spot welding. The welding time and the pressure of the electrodes at the welding point being automatically controlled. The inside faces of the panels are asbestos sprayed; this process in addition to its sound and heat insulation qualities also efficiently prevents internal condensation. All metal subject to corrosion is coated with a composition which is semi-plastic when dry and which will consequently neither crack nor peel off. The two power units one at each end of a four-unit coach consist of the Company's 220 h.p. 6-cylinder H-type Diesel engine direct-coupled to a main generator. The energy is transmitted to the bogies at each end of the train, which are each equipped with two motors. The engines are governed down to a maximum speed of 1,350 r.p.m. and it was to these engines that Mr. Nelson referred in his speech of welcome.

Another exhibit which created a great deal of interest was the first of the main line express locomotives for New Zealand; these locomotives weigh 84 tons and have a 4-8-2 wheel arrangement for 3 ft. 6 in. gauge. The operating voltage is 1,500 D.C. and a normal maximum speed of 60 m.p.h. will be obtained. Four 310 h.p. 750-volt motors are fitted and the electro-pneumatic control gear is arranged for multiple-unit operation. An interesting feature of these locomotives is the spring cup quill drive. With this type of drive the motor is spring borne and the unsprung weight of the driving system is therefore considerably reduced, and a higher axle loading is thus permissible. The locomotive is also fitted with an oil-fired boiler which supplies the heating and hot water supply to the train.

In addition to the express locomotives for the New Zealand Government Railways, six complete

Fig. 4.—84-ton Main Line Express Locomotive for New Zealand Government Railways.

Fig. 5.—Track wheels, showing spring cup Quill Drive—New Zealand Government Railways.

trains each consisting of motor and trailer coach for suburban traffic are in course of erection. Each motor coach is equipped with four motors of 165 h.p., electro-pneumatic control is employed and is arranged for multiple-unit operation up to three two-car units. For the Southern Railway, England, Diesel-electric locomotives for shunting work were in course of construction. These units are equipped with 350 h.p. "English Electric" Diesel engines direct coupled to 240 kW. main generators. The three axles are coupled and the maximum draw bar pull is 32,000 lbs. The Company's patented system of torque control enables the full output of the engine to be used over the working range giving tractive effects up to the adhesive limit.

For the Buenos Aires Great Southern Railway, and the Buenos Aires Western Railway, 99 Diesel-mechanical rail coaches are being built which represent the largest single order for this type of unit ever to be placed in Great Britain. The laden weight of each car is 22 tons. A system of electro-pneumatic control is fitted which permits multiple-unit operation with two or three units from one driving position. An exhaust hot boiler supplies hot water to heaters fitted in the passenger compartments. The underframes and body sections are fabricated by welding, the panels being riveted to the pillars.

The coaches are of different types—type "A" seats 39 second class passengers, type "B" 38 first class passengers, type "B.1" is a buffer coach with accommodation for 20 first class passengers, type "C" provides accommodation for 34 first and second class passengers and type "D" is a goods and postal wagon. This order was placed with the Company as a result of the liaison with the Drewry Car Company.

During the tour visitors had a comprehensive survey of the works and in addition to the contracts under construction a 36-seater trolley bus for the Moscow Municipality was in operation on the trolley bus test track, two works type Diesel-mechanical locomotives on the railway test track, whilst a 360 h.p. shunting locomotive of the Company's manufacture and lent for the occasion by the courtesy of the London, Midland & Scottish Railway Company was at work in the works' sidings.

Occasion was also taken to visit the Welding School where welding in its different forms was being carried out, and in addition a comprehensive exhibit of other products of the Company had been gathered together to remind our visitors that Preston Works is only one of the four great works which constitute the English Electric Company.

An opportunity was provided for representatives of the Technical Press to be present during the visits, and it is fitting here to reproduce an extract from one of the many kindly references made in the Technical Journals in the reports which followed the visits to Preston.

We extract from "The Railway Gazette" of July 9th, 1937 :—

"Probably the main impression gained by most

Fig. 6.—Truck shop with 0-6-0 100 H.P. Diesel-mechanical locomotive in foreground.

of the visitors was the tremendous extent to which electric welding can be used in the fabrication of railcar bodies, underframes and bogies. It was an experience to go through a large factory full of work without hearing a rivet hammer. The mechanical portions both of the Drewry Cars for South America and the train set for Ceylon have been built up almost entirely by electric welding, and full advantage of this method of construction has been taken to put metal just where it will take stress and to have no metal where there is no stress.

" Another feature which created much interest was the extremely simple yet efficacious design of the bogie frame structures for the various types of railcars, the use of welded sections giving great lateral rigidity without excessive weight, and providing a neat solution to the problem of finding room for the right design of such parts as brake and spring hangers."

The "English Electric" Overhead Busbar System.

Patent Nos. 442,640 : 442,641.

A new method of Power Distribution for Factories with individual motor drive.

Fig. 1.—Typical Overhead Busbar Installation in a Motor Works.
The runs of overhead busbar chambers with distribution fuse boxes feeding two runs of machine tools are seen on the top left and top right.

The outstanding new production of the Fuse Gear Section is the overhead busbar system for power distribution in factories containing machines with individual motor drive. Although only recently introduced, the system has been widely adopted, particularly by motor car and aeroplane engine manufacturers. The system consists of metalclad insulated busbars with plug-in points at frequent intervals, and arranged for securing to the roof or roof members of the machine shop. The busbar chamber is manufactured in 12 ft. lengths with connectors and fish plates so that the sections may be connected together to form any length of busbar chamber required. Each length contains six (alternatively nine) plug-in points into which fuse boxes containing "English Electric" high rupturing capacity non-deteriorating cartridge fuses can be plugged. Each fuse box has two earth-plugs which make contact in advance of the current-carrying plugs, thus allowing the fuse box to be inserted or withdrawn with the busbars "alive" and with perfect safety to the operator. A typical installation is shown in Fig. 1.

The system originated in connection with the motor car industry, where frequent re-arrangement of machine tools is necessitated by new production programmes. It was found that when a re-arrangement of machine tools was necessary,

although the fixing bolts for the new positions of the machines could be prepared in advance, the new electrical connections had to be made after the machines were moved to their new positions, and usually only a very short time was allowed for this. With the existing method of distribution where connections to each machine are made from centrally disposed distribution boards, the time allowed for the electrical change-over does not permit a permanent electrical installation to be made, and in order to have the machine tools operating in accordance with the production schedule, it is necessary to make temporary connections. These temporary connections tend to remain permanent as once the machines are in production it is found very difficult to arrange for a further shut-down in order to convert the temporary connections to permanent ones.

Various methods were therefore considered for producing a flexible method of power distribution which would allow for rapid change-over when the machines were moved to new positions. The Company in conjunction with plant engineers engaged in the motor car industry, have developed the present system, which has proved entirely satisfactory in practice. It is interesting to note that whereas this system was originally developed to cater for the machine tool shop which is frequently re-arranged, it has now been realised that the overhead busbar system has the further great advantage that it allows a new machine tool shop power distribution system to be designed and installed before the machine tools are in position, or even before their exact location is determined. Later, when the machine tools are erected the connections from the overhead busbar system to the motor starters can be quickly and readily made.

The detail construction is as follows :—

Busbar Chamber.

Sections of the busbar chamber are produced in 12-ft. lengths, and in order to be able to manufacture for stock only two sizes of busbar are supplied, i.e., $\frac{1}{2}$-in. diameter to carry 200 amperes and $\frac{9}{16}$-in. diameter to carry 250 amperes. Busbar chambers can contain 2, 3 or 4 busbars for double-pole, triple-pole, and triple-pole and neutral circuits. The number of plug-in points per 12-ft. length may be either six or nine as required. It will therefore be seen that there are twelve types of busbar chamber available as set out in the table below. This table also indicates the plug-in fuse boxes available for the different sizes of busbar chamber :—

Table Showing Sizes of Busbar Chamber Available.

Busbar Chamber containing	Dia. of Busbars.	No. of Plug Points per 12-ft Length.	30 amp. & 60 amp. Plug-in Fuse Boxes available.
2 Busbars	$\frac{1}{2}$ in.	6	D.P.
,,	$\frac{1}{2}$ in.	9	,,
,,	$\frac{9}{16}$ in.	6	,,
,,	$\frac{9}{16}$ in.	9	,,
3 Busbars	$\frac{1}{2}$ in.	6	D.P. & T.P.
,,	$\frac{1}{2}$ in.	9	,,
,,	$\frac{9}{16}$ in.	6	,,
,,	$\frac{9}{16}$ in.	9	,,
4 Busbars	$\frac{1}{2}$ in.	6	D.P., T.P. & T.P. & N.
,,	$\frac{1}{2}$ in.	9	,,
,,	$\frac{9}{16}$ in.	6	,,
,,	$\frac{9}{16}$ in.	9	,,

The main constructional feature of the busbar chamber is that the plug-in points for the fuse box are contained in the busbar supports. These moulded supports are fixed to two pressed-steel channels, each 12 ft. long, arranged in box formation, and secured by $\frac{3}{8}$-in. tie-bolts. Sheet-steel cover plates, formed slightly convex to prevent the accumulation of water and dirt, cover the top of the chamber, and a cork compound packing is employed to render it waterproof. Sheet-steel interplates are fixed to the underside of the channels between the mouldings, and these also are provided with a cork compound packing so that when the unit is built up it is completely dust-proof and moisture-proof. The busbars are insulated throughout their entire length, the insulation taking the form of paxolin tubes which are recessed into the moulded busbar supports. One end of each 12-ft. length of busbar is provided with fish plates for coupling to the adjacent length, together with connectors for the busbars. The busbars are secured in the connectors by "Allen" grub screws, and the bracing between the

Fig. 2.—Portion of Busbar Chamber with Plug-in Fuse Box in position.

adjacent busbar sections is such that the joint as a whole is as strong as the rest of the structure. The current-carrying sockets in the insulating busbar supports are deeply recessed to prevent accidental contact. The twin earth sockets in the moulded busbar supports are connected to the side channels. The construction of the busbar chamber is shown in Fig. 2, which also shows a plug-in fuse box in position.

Plug-in Fuse Boxes.

Plug-in fuse boxes are available in two current ratings, viz. :—30 amperes and 60 amperes, and for double-pole, triple-pole and triple-pole and neutral circuits. They accommodate the Company's "S" type porcelain fuse fittings to take standard "English Electric" high rupturing capacity non-deteriorating fuse cartridges from 2 amperes up to the maximum rating of the fittings. These fuses give visual indication when a fuse has operated, without the necessity of removing the handle. Fig. 3 illustrates a triple-pole 30-amp. fuse box with the earth plugs partly engaged in the earth sockets in the busbar support moulding.

Each plug-in fuse box comprises a dust-tight sheet-steel housing with side hinged cover secured by a spring clip fastener, containing plugs for connecting in the busbar sockets. Each fuse box has two earth-plugs which engage in advance of the current-carrying plugs. The earth-plugs, the ends of which are screwed, pass right through the busbar chamber and are secured in position by means of wing nuts. The construction of the current-carrying plugs is such that the earth-plugs cannot be inadvertently plugged into the "live" sockets. The underside of the fuse box is provided with a detachable plate which can be drilled for conduit or flexible armoured cable.

Incoming Units.—Incoming metalclad adaptor boxes are available, which can be bolted to any two of the tie-bolts along the run of the busbar chamber. These adaptor boxes contain cable sockets and connectors to the busbars, and are arranged to accommodate cable sealing boxes for paper-insulated cables approaching the busbar

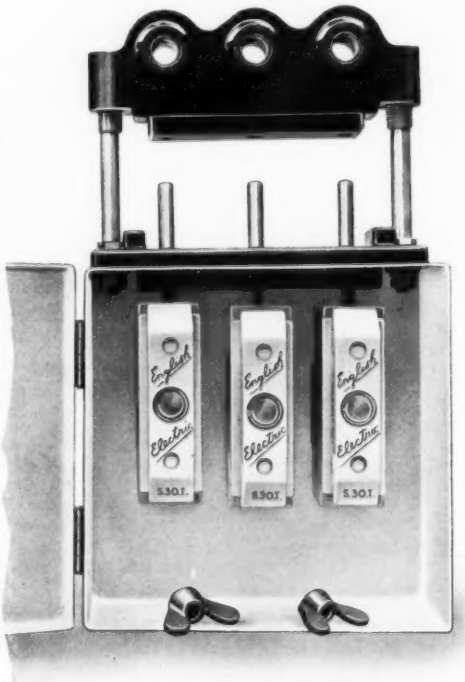


Fig. 3.—Plug-in Fuse Box with Earth Plugs partly engaged in Busbar Support Moulding.

chamber either vertically or horizontally in any direction or angle; alternatively the adaptor boxes can be arranged for conduit entry or for bushed holes.

Planning an Installation.—As the machines driven by the motors requiring a supply are almost invariably arranged in lines, it follows that the overhead busbar should be run above, and parallel to, the lines of machines, it usually being found that one run of overhead busbar chamber will feed two lines of machines. Therefore, in the average machine shop the overhead busbar system will consist of a number of parallel runs of overhead busbar, the length of each run being approximately the length of the line of machines to be supplied. Sometimes the busbars are arranged in the form of a ring main, and in other cases tee-off sections are necessary, but no hard and fast rule can be made and each scheme must be treated on its own merits. In the case of a length of busbar chamber arranged at right angles to the main run, the connections between the two sections are usually made by means of V.I.R. single-core taped and braided cables in

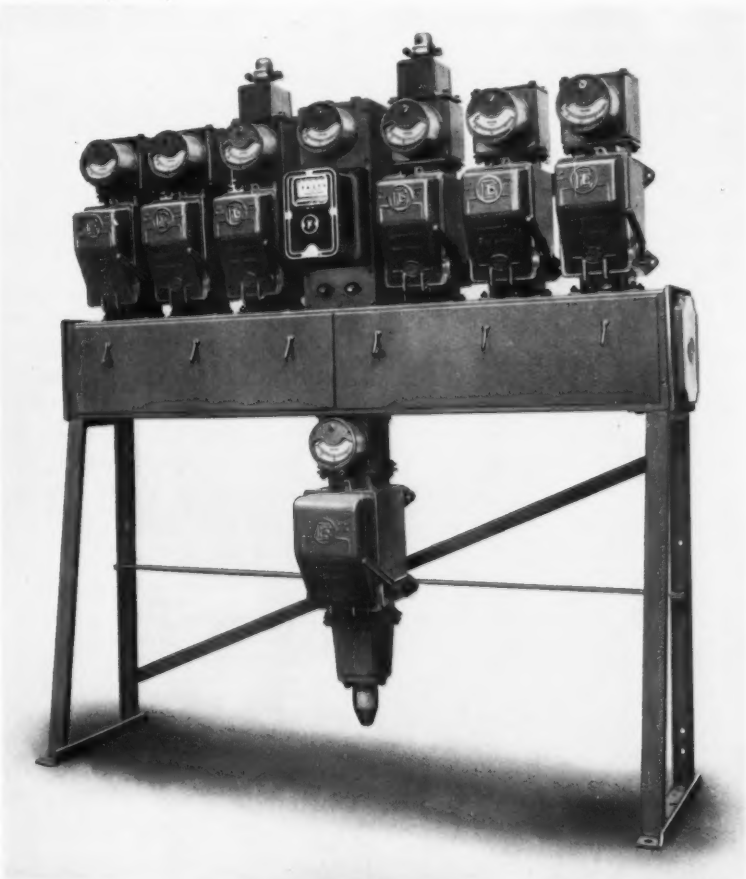


Fig. 4.—'Combination' Fuse Switchboard for control of Feeder Cables to Overhead Busbar Runs.

flexible metallic tubing, each end of the metallic tubing terminating in an adaptor box as already described. The number of feed-in points to the busbar chamber must be determined in accordance with the maximum number of plug-in points to be used and the loading thereof. If the runs are long, it is usually necessary to feed the run in the centre and not at one end. The current loading of the busbars per foot run will vary with the different types of machine shops to be supplied; for example, the loading of a typical machine tool shop of a motor car engine manufacturer worked out at 0.7 h.p. per foot run on a single line of machines, the horse-power being taken as the name plate rating of the motors used. This is approximately 1 ampere per foot run on a 440 volts three-phase supply for a single line of machines, consequently a double line of machines 200 feet long could be supplied from 200-ampere busbars providing the incoming supply is taken to the centre of the run. If large numbers of small motors are to be supplied, the busbar chamber containing nine points per 12-ft. length section will be necessary, but in the case of a shop containing large motors the busbar chamber with six points per 12-ft. section will usually suffice. It should be borne in mind when planning the installation that it is desirable that a number of plug-in points be left unused in order that additional supplies may be taken from these points as and when required.

Having ascertained the number of lengths of busbar chamber required and the number of feed-in points, it is then possible to determine the number of outgoing ways required on the substation board. The cables between the substation board and the feed-in points of the busbar chamber will usually consist of paper-insulated lead-covered and armoured cables run along the roof members of the building.

The most suitable form of substation board is a " Combination " fuse switchboard incorporating " English Electric " high rupturing capacity non-deteriorating cartridge fuses as illustrated in Fig. 4.

The great advantage of using " English Electric " fuses on the substation board is that graded operation between these fuses and the fuses in the plug-in boxes will be obtained, thus a fault on the outgoing side of the plug-in fuse box will always be cleared either by the motor-starter or by the fuses in the plug-in box, and will not be reflected back to the fuses on the substation board. This discrimination is due to the fact that the fuse cartridges, although of different ratings, have similar characteristics and also because these characteristics are retained throughout the life of the fuses by virtue of their non-deteriorating properties.

It is desirable that each motor is protected by a motor-starter fitted with overload devices. When selecting the size of fuse cartridge for the plug-in fuse box, the type of motor and type of starting must be taken into consideration to ensure that

TABLE SHOWING RECOMMENDED FUSE RATINGS.

B.H.P. of Motor.	Approx. Full-Load Current (Amperes) at 200 v.	Cartridge-Fuse Rating (Amperes)		Approx. Full-Load Current (Amperes) at 346 v.	Cartridge-Fuse Rating (Amperes)		Approx. Full-Load Current (Amperes) at 415 v.	Cartridge-Fuse Rating (Amperes)		Approx. Full-Load Current (Amperes) at 500 v.	Cartridge-Fuse Rating (Amperes)	
		A	B		A	B		A	B		A	B
1	3.5	10	6	2.0	6	6	1.7	6	6	1.4	6	4
3	10	30	15	5.75	20	10	4.8	15	10	4.0	15	10
5	14.25	50	25	8.25	25	15	7.0	25	15	5.7	20	10
7½	21.5	80	35	12.5	35	20	10.5	30	15	8.5	25	15
10	28	80	50	16	50	25	13.5	50	25	11	35	20
15	40	100	60	23	80	35	19	60	30	16	50	25
20	55	160	80	31.5	100	50	26	80	50	22	80	35
30	81	200	125	47	160	80	39	100	60	32.5	100	50
40	110	250	160	63	160	100	52	160	80	44	125	80
50	133	300	200	77	200	100	64	200	100	53	160	80
60	162	350	250	94	200	160	78	200	100	65	200	100
75	200	400	250	116	250	160	95	200	160	80	200	125

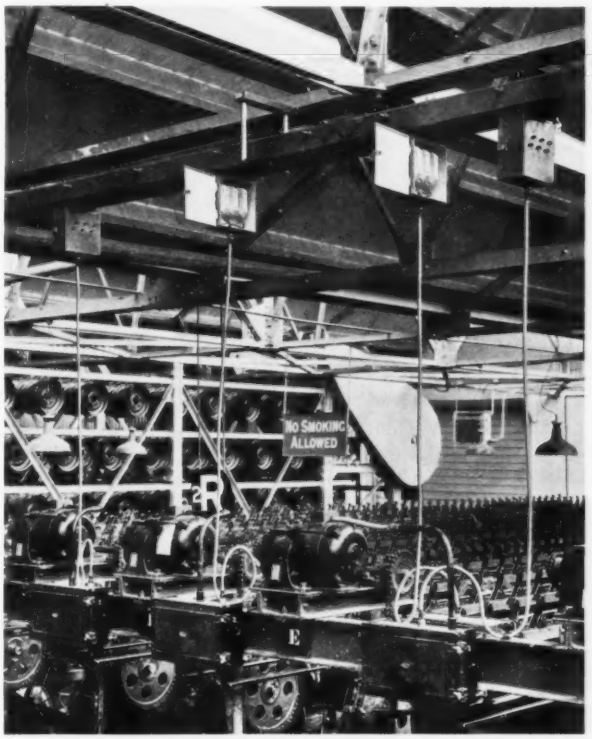
the rating of the fuses is such that they will not operate due to motor starting currents. Recommended sizes of fuses for various sizes of motors at different supply voltages are given in the table shown on page 239, it being noted that columns "A" refer to squirrel cage direct-on start motors and columns " B " refer to squirrel cage star-delta or auto-transformer start motors and wound rotor motors. If the fuse sizes are selected in this manner all overloads on the motors will be taken care of by the starter and in the event of a severe short circuit on the motor, or fault either in the starter or lead-down cables, the fuses in the plug-in box will operate. This arrangement is an ideal one from an operating point of view, inasmuch as the most frequent fault on a machine tool is an overload on the motor which will cause the starter to open, the fuses being unaffected. The operator can therefore close the starter immediately he has removed the cause of the overload, the loss of production time being reduced to a minimum.

Another important characteristic of " English Electric " high rupturing capacity non-deteriorating cartridge fuses is that under severe short-circuit conditions the speed of operation is much faster than the speed of opening of the starter, consequently if a severe electrical fault occurs in the motor or in the connection between the starter and the motor, the fuses will operate before the starter contacts separate, thus preventing burning of starter contacts or other damage to the starter.

Down Leads.

The down leads can consist of flexible armoured cable as shown in Fig. 5, or V.I.R. taped and braided cables in screwed conduit as shown in Fig. 1.

In the case of installations where it is anticipated that machines will be frequently rearranged, the flexible down-lead undoubtedly has a definite advantage, whereas if the installation of machines is expected to remain permanent V.I.R. cables in conduit may be used. An interesting design of flexible down-lead cable has recently been developed. This consists of twin or three-core tough rubber sheathed cable wrapped with oil-resisting tape and finally braided with tinned copper wires. With this type of cable the tinned copper wires on the outside of the cable can be used as the earth conductor. It is, however, necessary to protect mechanically this cable when near floor level, and this may be effected by running the cable in conduit from the motor-starter to a point about 6 ft. above floor level. The portion of the cable inside the conduit has the braiding removed, the braiding being terminated in a special cone clamp screwed into the top of the conduit. A similar clamp for the braiding is fitted to the underside of the fuse box. When this form of cable is used, the conduit from



(Illustration by courtesy of Messrs. Humber Ltd.)

Fig. 5.—An Overhead Busbar Installation using Armoured Flexible Down Leads.

the starter should be permanently attached to the machine so that when the machine is moved, the conduit moves with it.

In conclusion, it is hoped that this description of the " English Electric " overhead busbar system will be of service to engineers who have to deal with the problem of power supply to machines with individual motor drive, and we would emphasise that, although a relatively new production, the system has been installed in large quantities with complete and entire satisfaction.

Railway Electrification in Poland.

At the restoration of Poland's independence in 1918 the country's railways were in a precarious condition. They had been seriously damaged during the war and the organisation in three separate systems was very unsatisfactory. Considerable repair and re-organisation were therefore necessary and a comprehensive policy of unification and modernisation was adopted. Under this policy one of the most important improvements undertaken was the construction of a new route through the city of Warsaw and the electrification of this line and first stage of the Warsaw suburban railway system. This work is now nearing completion. Electrical service on the through route and a considerable part of the suburban system was inaugurated by the Polish Vice-Premier on December 15th, 1936.

The City of Warsaw, in addition to being the capital and principal city of Poland, with a population of 1,300,000, forms an important link in railway communications between the U.S.S.R. and the west. Previous to the recent developments the city was served by four terminal stations, two on each side of the Vistula, and these were connected solely by a long loop line, which was the only route for through traffic across the river. Each terminal served its suburban area and the Central Station, in addition, accommodated the main line expresses. Thus the Warsaw traffic was characterised by excessive terminal operation and no through suburban traffic.

The solution of these difficulties was obviously to construct a line through the heart of the city to connect the Central and Eastern stations, thus enabling the passenger service to be dealt with at " through running " stations, with the consequent avoidance of terminal troubles.

To carry out this scheme it was necessary to construct a tunnel underneath part of the city west of the Vistula, and owing to the difficulty of providing ventilation it was clear that electric traction would have a great advantage over steam. To electrify the short new line (7.5 km.) only would obviously have been disadvantageous on financial and operating considerations, but investigation showed that suburban and local traffic density was sufficient to justify general electrification to a radius of about 40 km. A special Commission reported in 1922 that appreciable economies could be effected by electrification ; technical opinion later confirmed this view, and a detailed scheme was drawn up.

In 1933 with the help of the English Electric Company and the Metropolitan-Vickers Electrical Company, it was found possible to finance the first part of the scheme. This covered the electrification of the new through line and three important lines radiating from the city to Zyrardow (43 km.) to Minsk (40 km.) and to Otwock (27 km.) and this work was commenced under a contract signed in August, 1933, with these two companies as main contractors. The work has been carried on by a Committee of the Contractors in close co-operation with the Polish Ministry of Communications. The amount of the contract was approximately two million pounds sterling, of

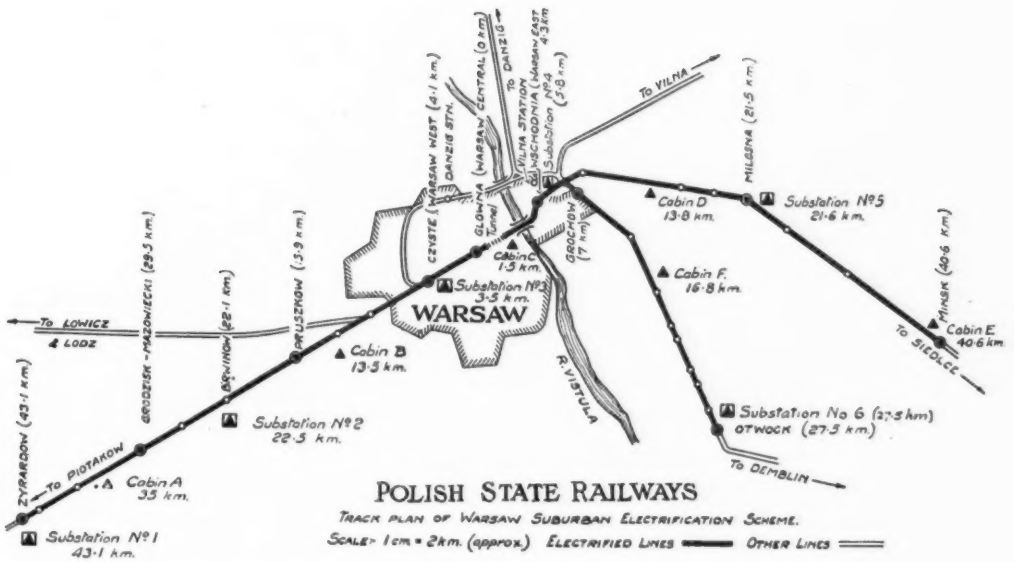


Fig. 1.

which roughly one million has been expended in Poland on civil and electrical work.

The electrical equipment covered by the contract included six rectifier substations, the overhead line equipment, six 2,200 h.p. electric locomotives, and the complete electrical equipment of seventy-six three-coach trains and four switching locomotives. The overhead line work has been carried out by British Insulated Cables, Ltd., acting as principal sub-contractor. The switchgear and a considerable amount of accessory equipment have been supplied by Polish sub-contractors.

The accompanying map (Fig. 1) shows the lines electrified under the present scheme and the positions of the substations and track-sectioning cabins. It also shows the loop line from Warsaw East to Warsaw West station thus illustrating the advantage of the new line through the city.

The electrical operation is at 3,000 volts D.C. The selection of this high voltage, which has the advantage of low distribution losses with a minimum number of substations, was influenced by consideration of the length of lines to be served and the nature of the traffic, consisting of both suburban motor-coach trains and powerful main line locomotives. Advantage has been taken of the latest developments in rectifier equipment and high voltage D.C. equipment for multiple unit coaches and locomotives, in which the contractors have very extensive experience.

Substations and Track Sectioning Cabins.

Energy for the operation of the motor coaches and locomotives is delivered in the form of direct current from six rectifier substations at 3,300 volts on the bus bars. These substations, in turn, draw energy at 35,000 volts, 3-phase, 50 cycles, from a large supply network fed from Pruszkow and Warsaw power stations.

A careful analysis of the power requirements of the electrified lines revealed that these requirements could be met most advantageously by the provision of 13 mercury arc rectifier units installed in six substations located at suitable points along the line. Substations 1 and 5, each contain two 2,000 kW. rectifier units; substations 2, 4 and 6 each contain two 2,500 kW. units; and substation 3 has three 2,500 kW. units.

Track sectioning cabins, containing high speed d.c. circuit breakers, have been provided between

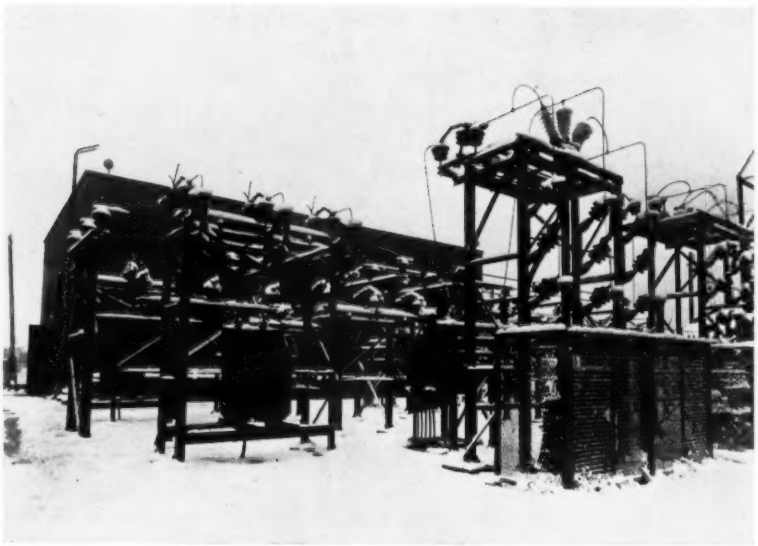


Fig. 2.—Outdoor Switchgear at No. 3 Substation.

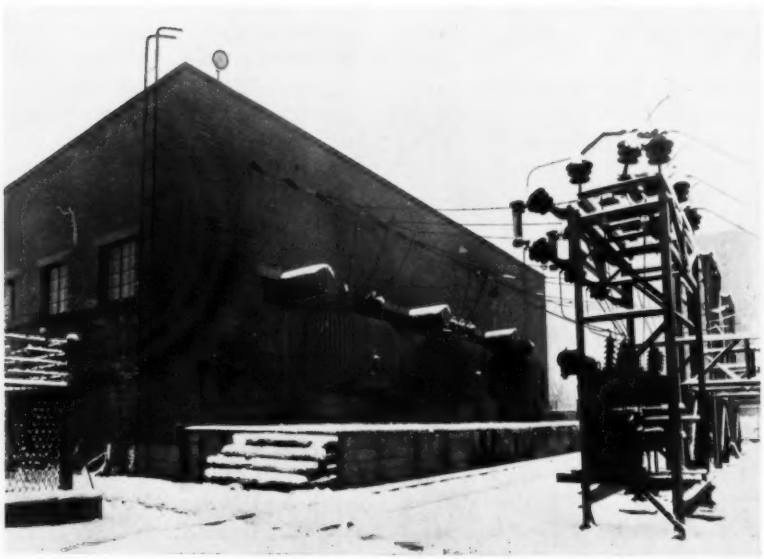


Fig. 3.—Typical Transformers for 2,500 kW. Rectifier.

adjacent substations for the purpose of isolating sections of the line in the event of trouble or repair work on any one or more sections.

On the E.H.T. side of the substations continuity of supply is ensured by the provision throughout of two or more incoming feeders, enabling each substation to draw its energy from Pruszkow or Warsaw Power Stations, or from both. Normally the power stations operate in parallel and represent a combined capacity of approximately 143,000 kVA. of which the maximum rated load of the rectifier substations is some 35,000 kVA.

Substations 1, 3 and 6 have been equipped by the English Electric Company, Ltd., and substations 2, 4 and 5 by the Metropolitan-Vickers Electrical Company, Ltd., the A.C. switchgear being supplied by Polish sub-contractors. The buildings for all substations were provided by the Polish State Railways.

At each substation the incoming 35 kV. supply feeders are taken to outdoor steel structures where they are connected to isolating switches, lightning arresters, potential and current transformers, and led to the oil circuit-breakers and bus bars. From the E.H.T. bus bars leads are taken through isolating switches and circuit-breakers to the outdoor rectifier transformers.

Fig. 2 shows a general view of the outdoor switching arrangements, fairly typical of all substations. The oil-circuit breakers shown have a three-phase rupturing capacity of over 500,000 kVA. The housing of the outdoor controls of these breakers encloses a small electric heater, so that reliable operation of the mechanism is obtained during winter when very low ambient temperatures occur.

Protection of the incoming feeders is afforded by impedance/time (distance) relays and earth leakage indication only is provided, since the system is designed to operate with the neutrals earthed through arc suppression coils. Tripping of the rectifier oil-circuit breakers is effected by overload relays with inverse time limit characteristics, as well as by relays which operate instantaneously under short-circuit conditions.

The rectifier transformers, which are of the outdoor self-cooled type, are three-phase, star connected on the primary side, and six-phase fork connected on the secondary. The transformers are also equipped with a tertiary six-phase star connected winding for baking-out the rectifiers at low voltage. The terminals of this winding are adjacent to the corresponding terminals of the secondary winding, so that the minimum amount of labour is involved when changing over the anode leads from rectifier to bake-out service during erection or overhaul periods. Fig. 3 shows three typical transformers for 2,500 kW. rectifier equipments at No. 3 substation. From the secondary terminals of the rectifier transformers, bare copper leads are taken through leading-in insulators to the six-anode steel-tank rectifiers situated inside the substation buildings.

The rectifiers are capable of sustaining overloads of 25 per cent. for 15 minutes and 200 per cent. momentarily. Fig. 4 illustrates a typical 2,500 kw. rectifier.

Cooling of the rectifiers is effected by passing water through the jackets, cathode, anode plates,

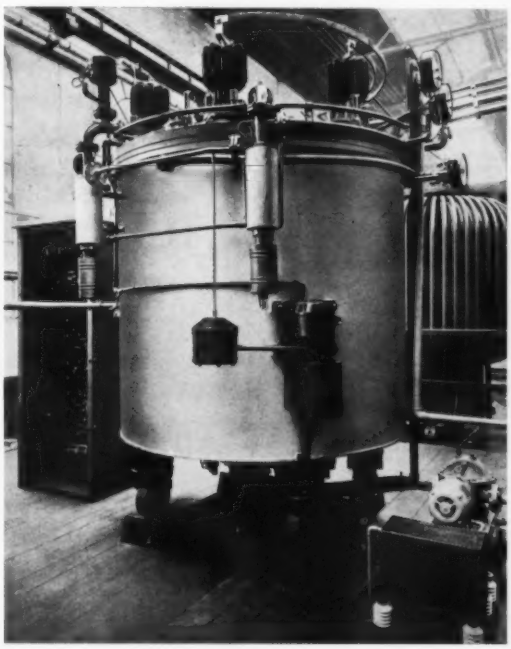


Fig. 4.—Typical 2,500 kW. Rectifier.

etc., of the rectifiers and circulating this water by means of a small pump through air-blast re-coolers. The fan for delivering the air-blast is driven by a motor which is cut in and out by a thermostat in the rectifier cooling water circuit.

The rectifiers are all provided with vacuum pumping sets, comprising high and low-vacuum pumps, the former being of the mercury vapour type and the latter of the self-cooled rotary type. These pump sets are switched in or out, according to the vacuum obtaining in the rectifier, by means of a relay operating in conjunction with a Pirani vacuum gauge. A separate air-blast recooling equipment is provided for the high-vacuum pump which may be running when the rectifier is out of service, thus obviating the necessity of running the larger recooler continuously for this purpose.

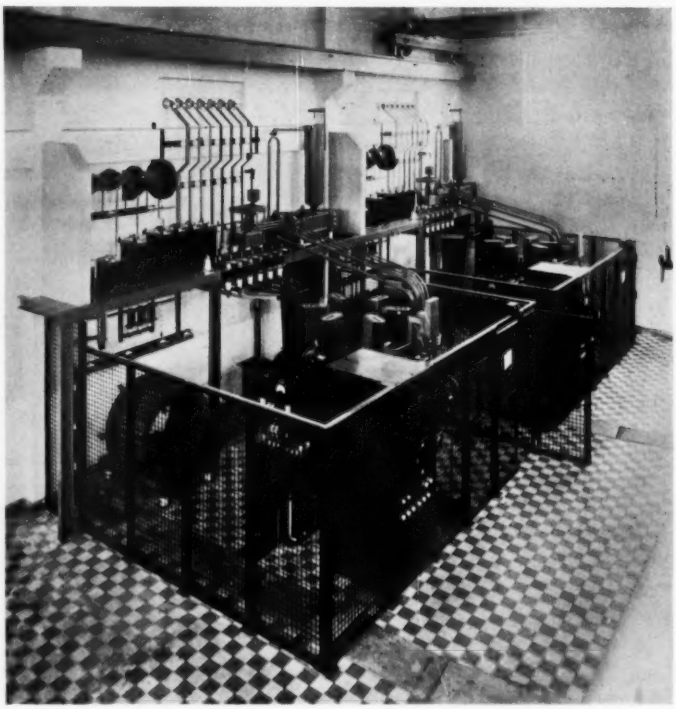


Fig. 5.—Interior of No. 4 Substation.

Fig. 5 gives a general view of the interior of No. 4 substation (Warsaw East). The tops of the rectifier recoolers are visible behind the rectifiers, and the vacuum pump recoolers are to be seen on the gallery.

The guaranteed overall efficiencies of the rectifier units, including transformer and auxiliary losses, are worthy of mention, being as follows :—

Load.	5/4	4/4	3/4	2/4	1/4
Effy. %	96.07	96.6	96.82	96.72	95.57

The actual efficiency figures measured on test by the method of summation of losses appreciably exceed the guaranteed figures.

On the D.C. side the rectifiers are protected by high-speed breakers of Metropolitan-Vickers manufacture. These breakers are designed for reverse current tripping and are installed in the lead between the cathode and D.C. bus bars. The breakers are located in stonework cells on a gallery together with the D.C. isolating switches, and controlled from panels located below. The control panels and D.C. isolating switches were manufactured in Poland.

The outgoing D.C. feeders are also equipped with similar high speed breakers. These are arranged for auto-reclosing and overload tripping in the forward sense, i.e., when excessive current flows outwards from the substations. A bus tie and feeder testing equipment is provided and so arranged that it can be connected in circuit in the place of any one of the feeder breakers, when necessary.

(To be concluded in the next Issue.)

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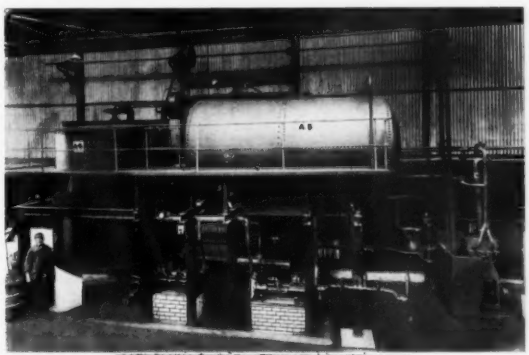

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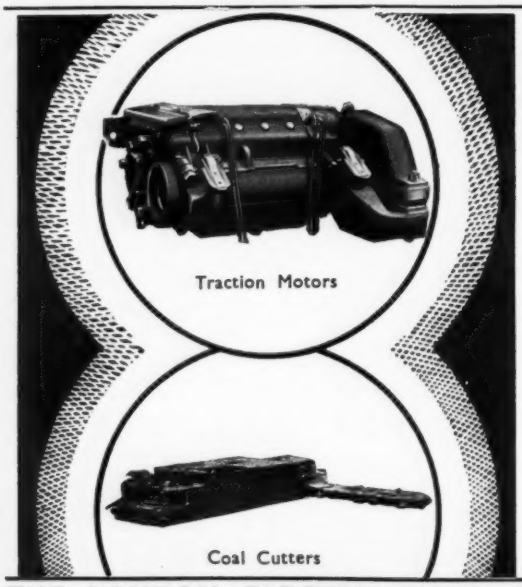

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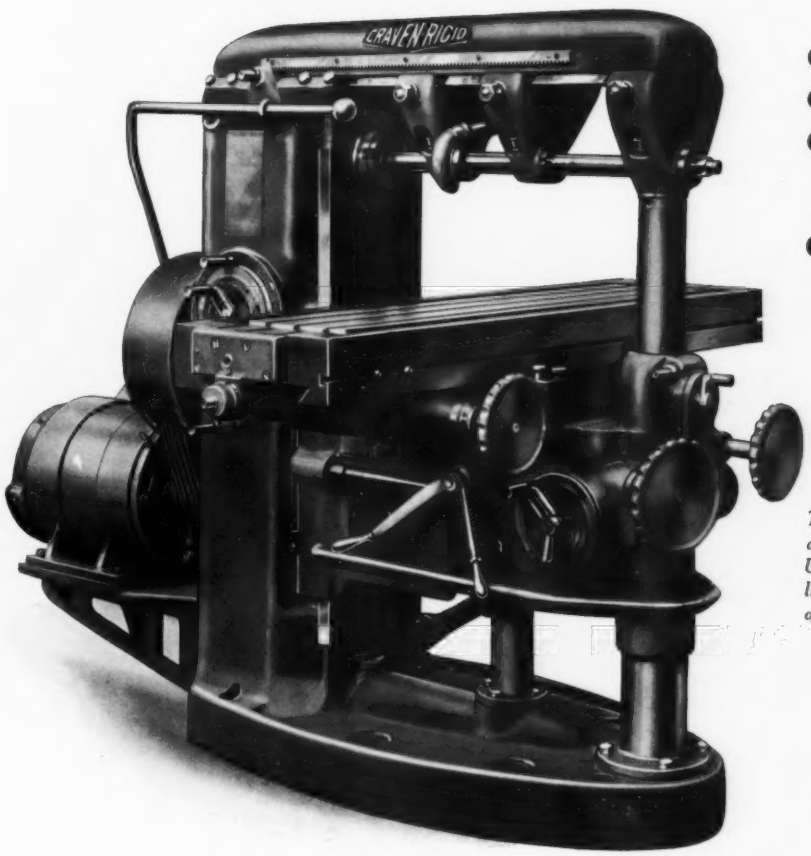

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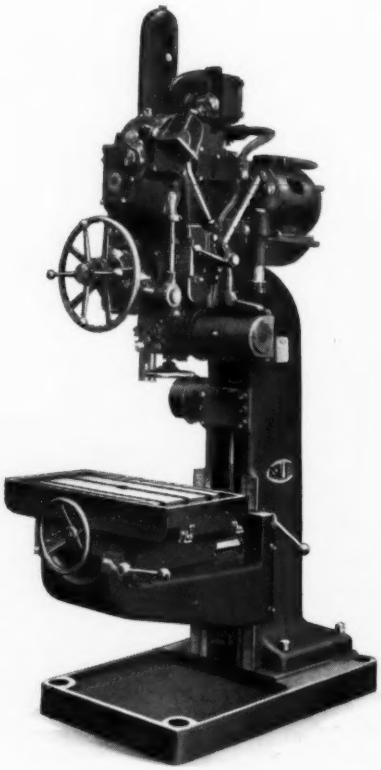

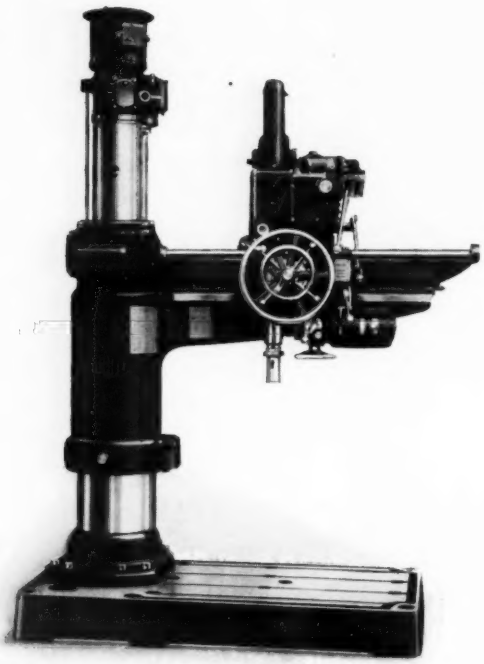

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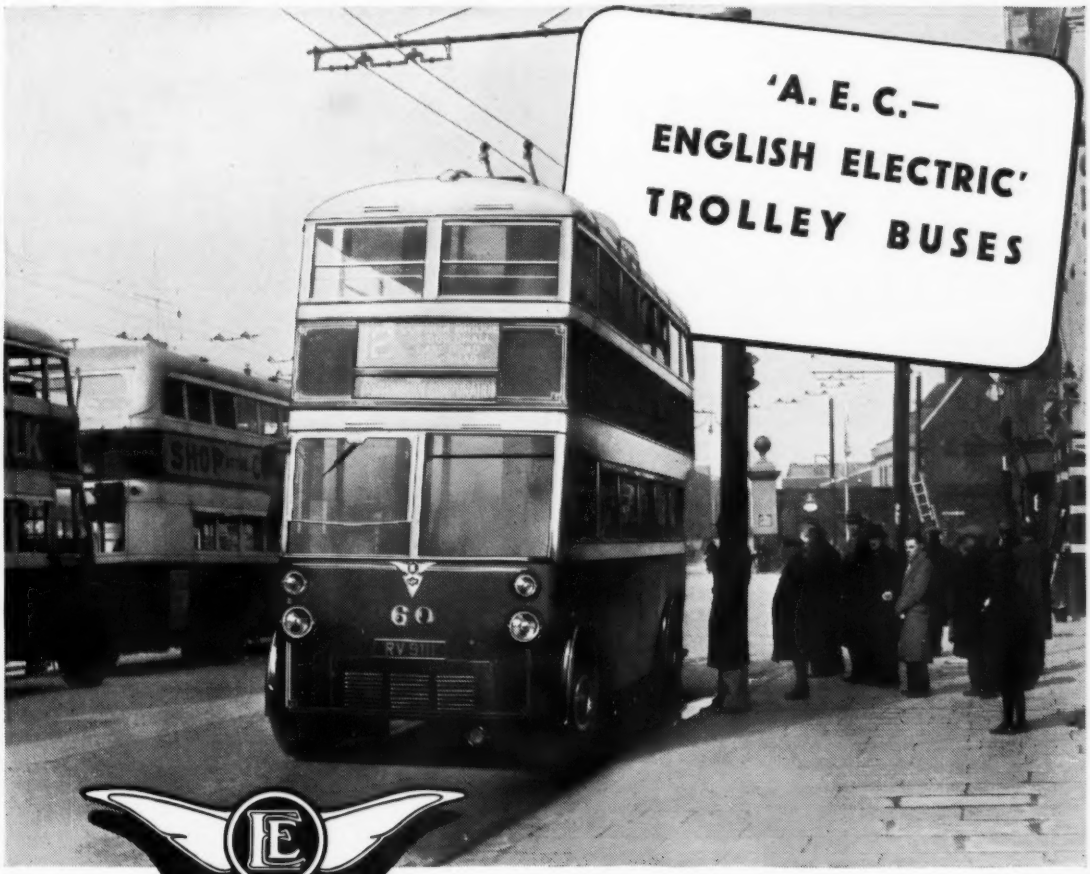

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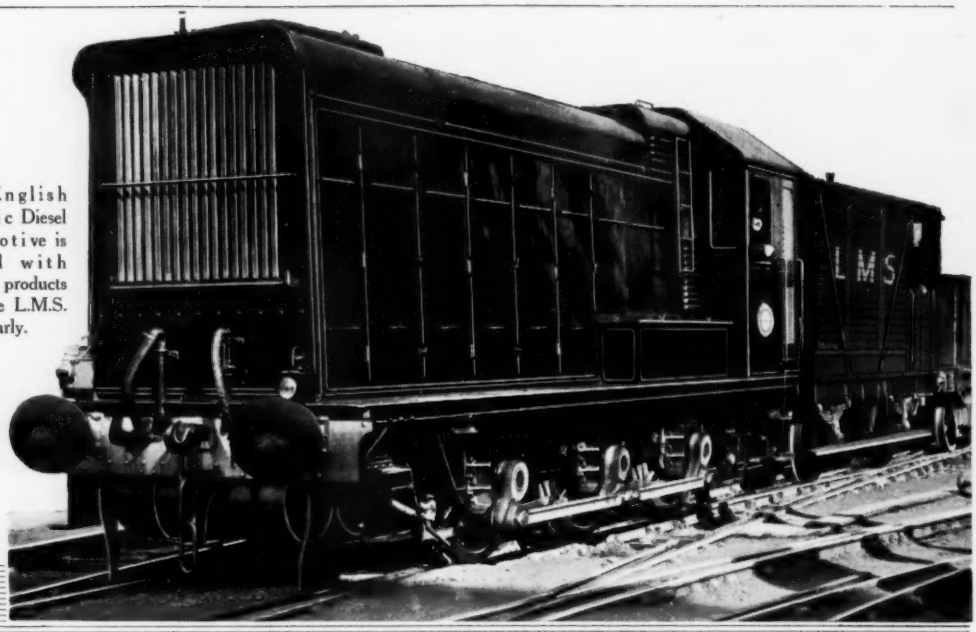

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